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(54) **ENVIRONMENTAL-BASED DEVICE
OPERATION**

(75) Inventors: **Michael Allen Seigler**, Eden Prairie,
MN (US); **John West Dykes**, Eden
Prairie, MN (US)

(73) Assignee: **Seagate Technology LLC**, Cupertino,
CA (US)

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None
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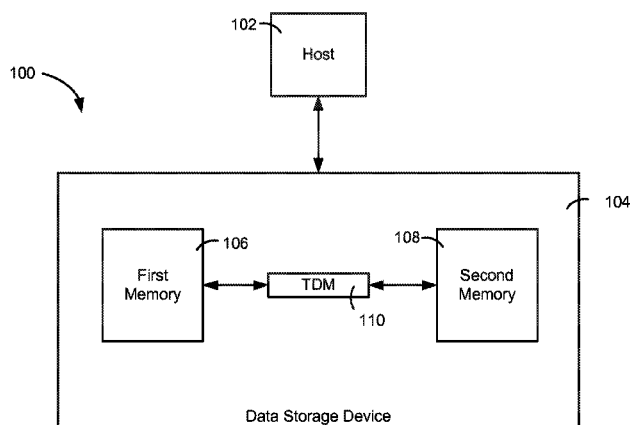
Primary Examiner — Kevin Verbrugge

(74) *Attorney, Agent, or Firm* — Cesari & Reed LLP; Kirk A. Cesari; Christian W. Best

(57) **ABSTRACT**

The disclosure is related to systems and methods for temperature-based device operation. In one example, a device may include a first memory and a temperature detection module adapted to measure a temperature of the device and modify a data storage behavior of the first memory based on the temperature. The device may further comprise a second memory, and the temperature detection module may direct that data be written to the first memory less frequently, and be written to the second memory more frequently when a threshold temperature is exceeded. The temperature detection module may also implement operating limitations for the device when a threshold temperature is exceeded, such as restricting execution of background diagnostics or implementing other operating limitations. In some embodiments, other environmental factors such as humidity, altitude, air pressure, physical shock, or other factors may be monitored and the device operation may be modified based on those factors.

20 Claims, 4 Drawing Sheets



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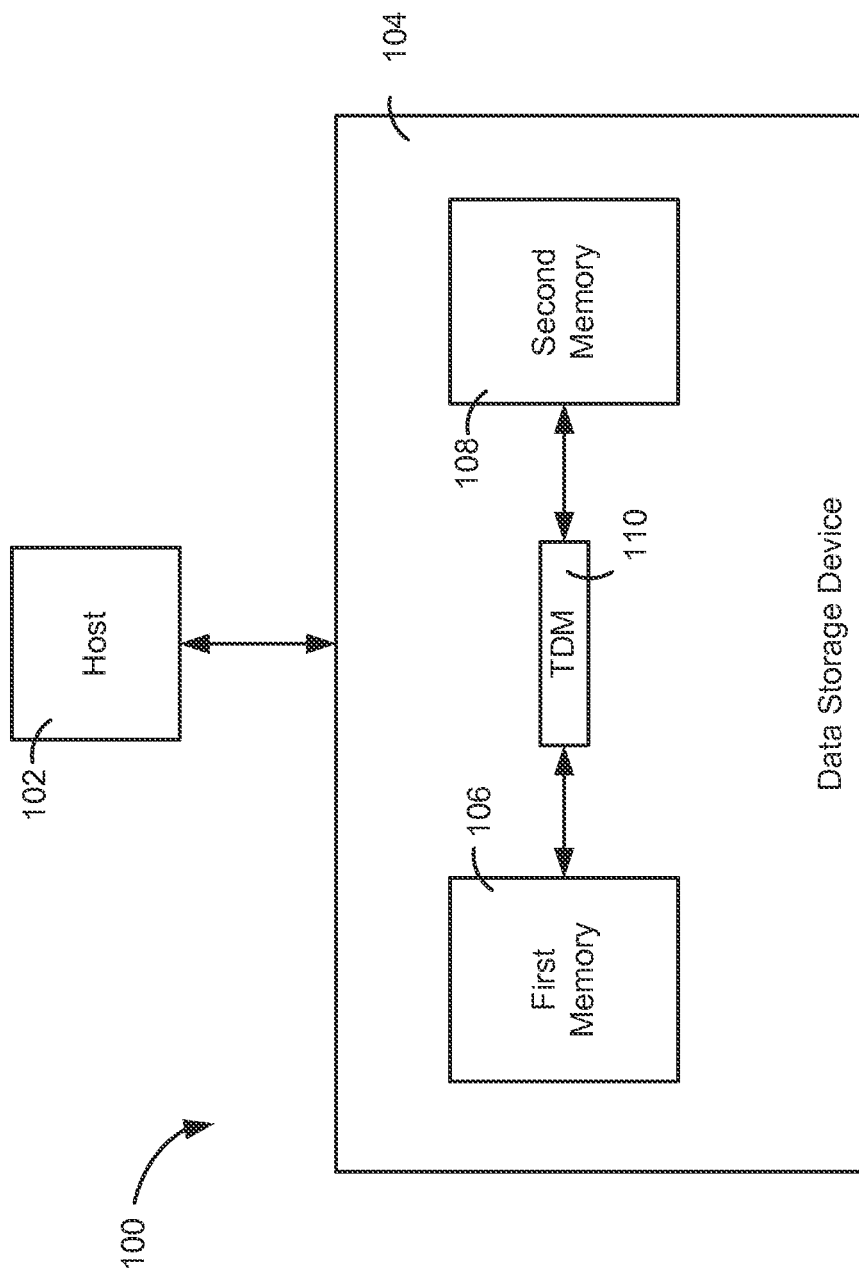


FIG. 1

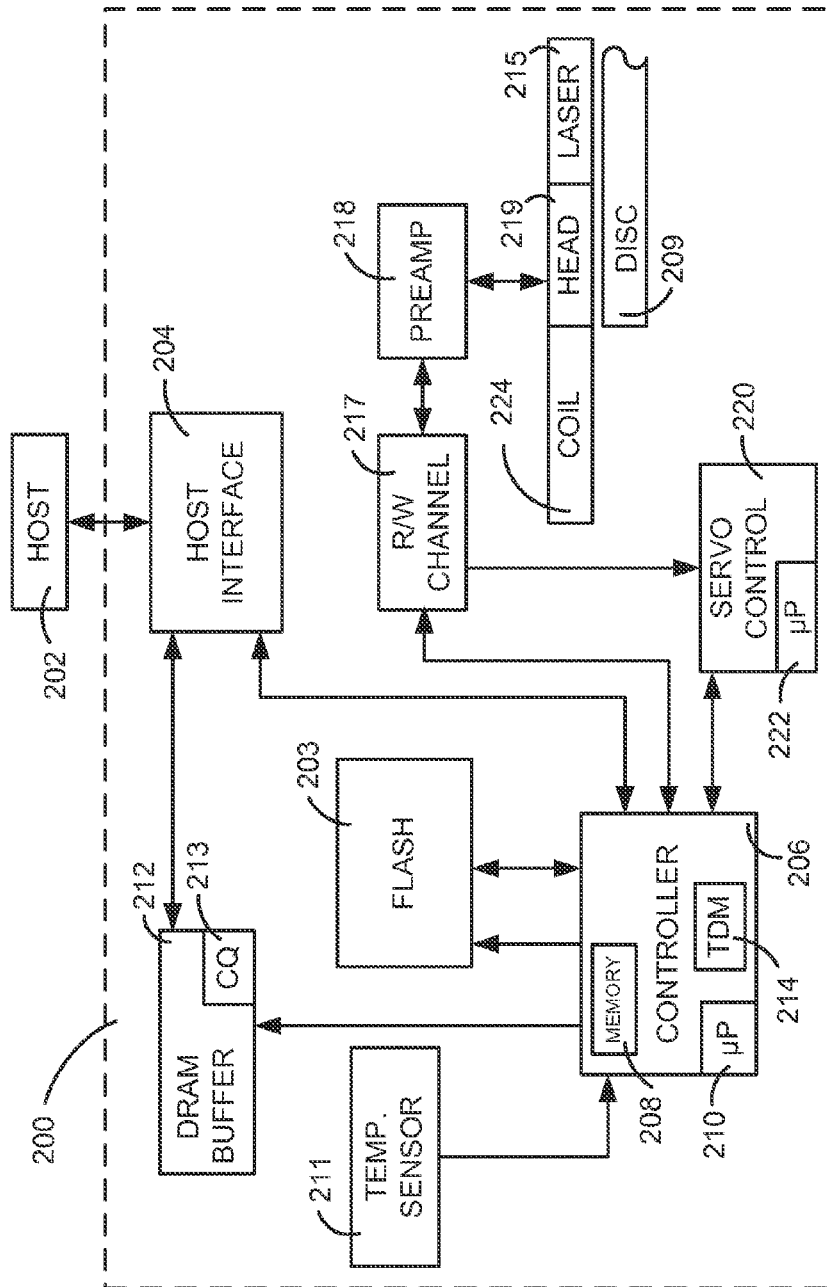
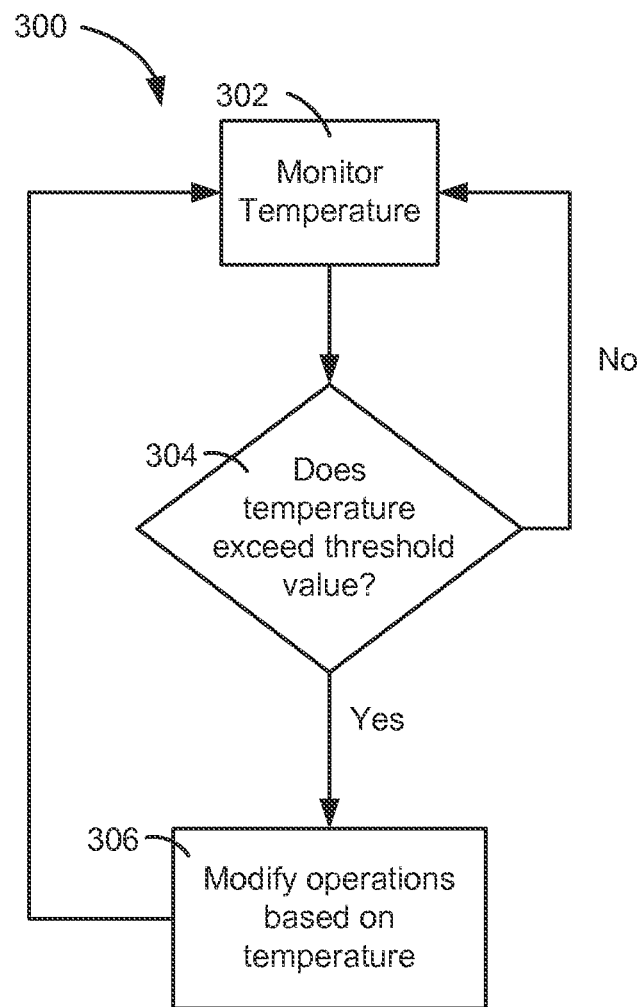


FIG. 2

**FIG. 3**

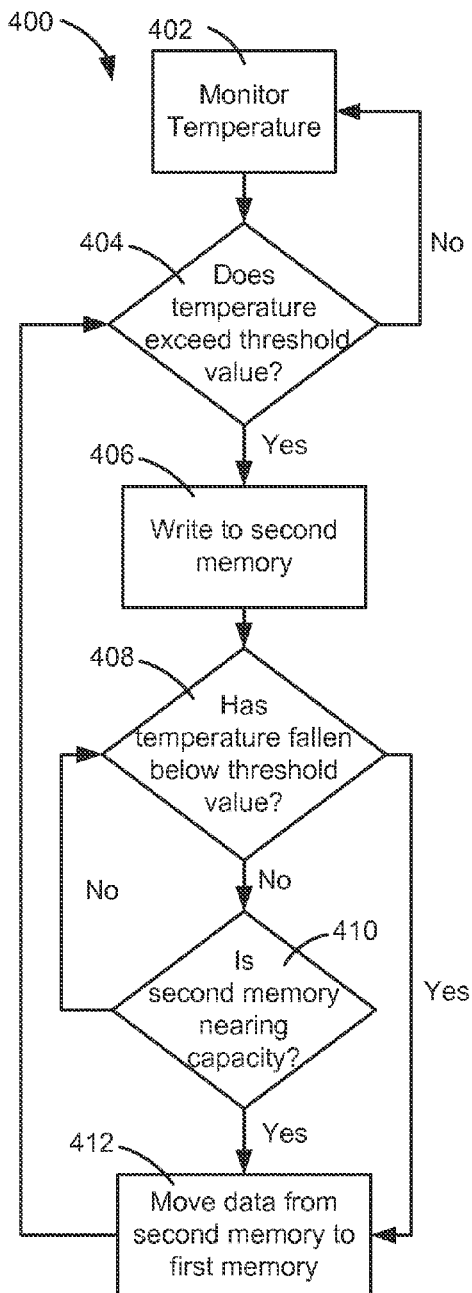


FIG. 4

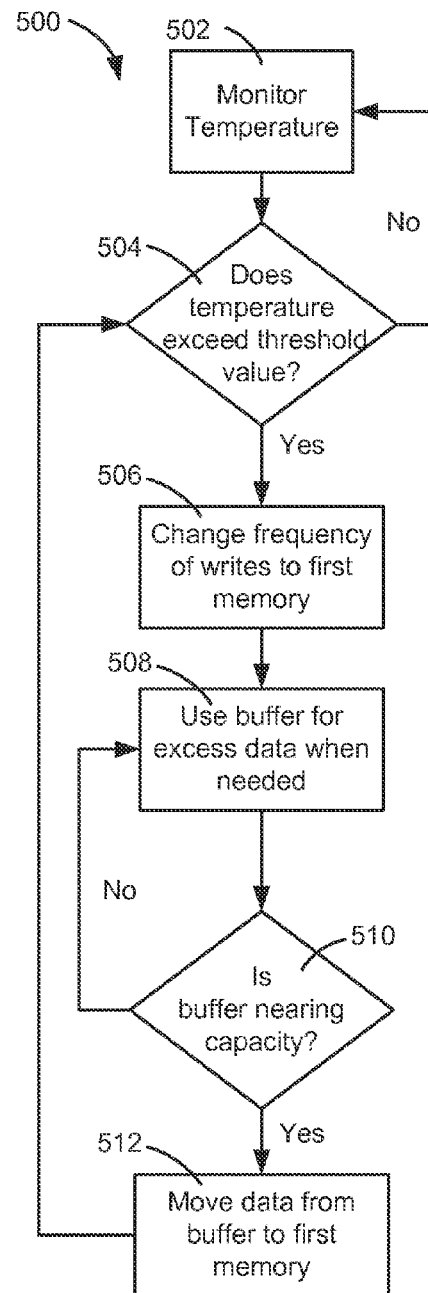


FIG. 5

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ENVIRONMENTAL-BASED DEVICE OPERATION

BACKGROUND

Data storage devices may perform differently at different temperatures. For example, higher temperatures may compromise the reliability of data stored to some storage mediums, or may affect the performance or durability of component parts in the device.

SUMMARY

A device may comprise a first memory and a temperature detection module (TDM). The TDM may be adapted to measure a temperature of the device and modify a data storage behavior of the first memory based on the temperature.

In another embodiment, a device may comprise a controller configured to detect a temperature of a data storage device, and to write data to a second memory if the temperature exceeds a threshold value.

Another embodiment may be a method comprising detecting a temperature of a data storage device and modifying the operation of the data storage device based on the temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of an illustrative embodiment of a system for temperature-based device operation;

FIG. 2 is a diagram of another illustrative embodiment of a system for temperature-based device operation;

FIG. 3 is a flowchart of an illustrative embodiment of a method for temperature-based device operation;

FIG. 4 is a flowchart of an illustrative embodiment of a method for temperature-based device operation; and

FIG. 5 is a flowchart of an illustrative embodiment of a method for temperature-based device operation.

DETAILED DESCRIPTION

In the following detailed description of the embodiments, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration of specific embodiments. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present disclosure.

FIG. 1 shows a diagram of an illustrative embodiment of a system for temperature-based device operation, generally designated **100**. The system **100** may include a host **102** and a data storage device (DSD) **104**. The host **102** may also be referred to as the host system or host computer. The host **102** can be a desktop computer, a laptop computer, a server, a personal digital assistant (PDA), a telephone, a music player, another electronic device, or any combination thereof. Similarly, the DSD **104** may be any of the above-listed devices, or any other device which may be used to store or retrieve data. Further, the DSD **104** can be a stand-alone device not connected to a host **102**.

The data storage device **104** can include a first memory **106**, a second memory **108**, and a temperature detection module (TDM) **110**. In some embodiments, the first memory **106** may be a nonvolatile storage medium of the DSD **104**, such as a disc data storage medium, and the second memory **108** may be a data buffer or cache, where the second memory **108** may be less influenced by variations in temperature than the first memory **106**. For example, the DSD **104** may be a hybrid disc

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drive with a disc data storage medium and a non-volatile solid state memory, such as a Flash memory. The first memory **106** and the second memory **108** can be any form of volatile or non-volatile memory capable of storing data, such as Flash memory, ROM, RAM, DRAM, SRAM, other solid state memory, magnetic memory, optical memory, or any combination thereof.

The temperature detection module **110** can monitor the temperature of the DSD **104** or component parts of the DSD **104**. The TDM **110** may be software, a programmable controller, a circuit, a CPU, or any combination of elements capable of sensing or processing temperature information. The TDM **110** may be designed to monitor the temperature of a single or multiple locations or elements of the DSD **104**. The TDM **110** may also be designed to determine a length of time the DSD **104** or a component part operates beyond a temperature threshold.

The TDM **110** may be configured to modify a behavior of the DSD **104** if the TDM **110** determines that a temperature threshold has been exceeded, or if a temperature threshold has been exceeded for a designated length of time. For example, the TDM **110** may modify the behavior of the DSD **104** if the DSD has been operating above a threshold temperature of 70° C. for over two minutes. The behavior may be modified so as to impose operating limitations on the DSD **104**, such as restricting background diagnostics, reducing processing speeds, reducing a frequency of commands executed up to or including not processing user commands at all, reducing a motor speed or seek speed, stopping spinning of one or more magnetic storage discs entirely, or entering a power saving mode. Another example of modified behavior may be to process commands only within certain data zones of a memory of the DSD **104**, thereby restricting seek length and power consumption. As a means of implementing this example, data could be divided into different classifications and mapped to different disk locations depending on the classification.

The TDM **110** may be configured to keep a log of time & temperature. This log may be used to focus diagnostics on certain components of a DSD **104**, to warn users of how long a device or component has been operating above a threshold temperature, to anticipate impending device or component failures, to accumulate data regarding component or device operation at or above threshold temperatures, or for other purposes or any combination thereof.

Further, the TDM **110** may modify how data is recorded or read by the DSD **104** by changing a frequency or destination of data storage behavior. The term 'frequency,' as used herein, refers to how often a behavior is performed. As an example of modifying read or write behavior, when the threshold temperature has been exceeded the TDM **110** may direct that data be written to the first memory **106** less frequently, including that data not be written to the first memory **106** at all. Data not written to the first memory **106** may be written to the second memory **108**. For example, the host **102** may send data with a Logical Block Address (LBA) mapped to a physical location of the first memory **106**, but if the TDM **110** detects that the threshold temperature has been exceeded it may direct that data be written to the second memory **108** instead.

The TDM **110** may implement a behavior mode where data may be read from a first memory **106**, but not written to the first memory. If the TDM **110** determines that the temperature has fallen below the temperature threshold (e.g. 60° C.), or fallen below a second, lower temperature threshold (e.g. 55° C.), the TDM **110** may direct that any data written to the second memory **108** be moved to the first memory **106**. If the TDM **110** determines that the second memory **108** is approximately at capacity, it may likewise direct that data stored in

the second memory **108** be moved to the first memory **106**. The data could be organized in the second memory **108** so that data could be moved to the first memory **106** in an efficient manner, such as by a continuous write operation. In some embodiments, a DSD **104** operating in this fashion may write data at or near peak performance while minimizing operations that may be negatively influenced by a high temperature. As an example, some data storage mediums may be more susceptible to write errors due to high temperatures than other data storage mediums, so switching between two storage mediums at high temperatures may improve data storage reliability.

A TDM **110** could be adapted to monitor for a multiplicity of temperature thresholds, with different thresholds resulting in the TDM **110** modifying the behavior of the DSD **104** differently based on one or more corresponding thresholds. For example, if a first threshold is passed (e.g. 60° C.), the TDM **110** may limit background diagnostics; if a second temperature threshold is passed (e.g. 70° C.), the TDM **110** may restrict write operations to the first memory **106**; and if a third temperature threshold is passed (e.g. 90° C.), the TDM **110** may shut down the DSD **104** entirely. In some embodiments, the TDM **110** may monitor if certain high temperature thresholds are exceeded (e.g. 90° C.) at which the integrity of one or more components of the DSD **104** may be compromised, and adjust device behavior accordingly.

The TDM **110** may alter how the DSD **104** stores data if the temperature threshold has been exceeded. The TDM **110** may be implemented in a hybrid DSD **104** having a magnetic disc with heat assisted magnetic recording (HAMR) technology and a nonvolatile solid state memory, where the TDM **110** may be configured to monitor a temperature of a laser element of the HAMR technology. If the TDM **110** detects that a temperature threshold had been exceeded, or optionally if the temperature threshold had been exceeded for a specific length of time, the TDM **110** may direct that data, which may initially be intended to be written to the magnetic disc, be recorded to the nonvolatile solid state memory rather than to the magnetic disc. In some embodiments, data may initially be intended for a specific data storage medium based on a logical block address received from the host **102**, the logical block address can have an associated physical location at which to store the data associated with the logical block address. The physical location of the data associated with the logical block address may be initially associated with a specific data storage medium, such as a magnetic disc.

In other embodiments, the TDM **110** may direct that data be written to the magnetic disc less frequently, and written to the nonvolatile solid state memory more frequently. If the TDM **110** determines that the temperature has fallen below a second threshold, or if the nonvolatile solid state memory is nearing capacity, the TDM **110** may direct that the data stored to the nonvolatile solid state memory be moved to the magnetic disc. Limiting operation of the HAMR technology, including the laser, by not storing data to the magnetic disc may extend an operating life of the laser and the DSD **104**.

The TDM **110** may continually monitor the temperature, or may monitor the temperature or otherwise operate based on other circumstances such as: monitoring initiated by a user; monitoring initiated by other software or hardware component(s); monitoring initiated based on time intervals, such as every thirty seconds; monitoring initiated based on a period of continuous or intermittent data writes; any other circumstances that could trigger a temperature monitoring operation; or any combination thereof.

As an example, the TDM **110** may be designed to display information to a user and allow user oversight of the operation

of the TDM **110**. The TDM **110** could cause a display to show the temperature or an indicator to a user, and the user could manually direct whether the TDM **110** implements behavior modifications for the DSD **104**, or select which behavior modifications the TDM **110** implements. In some embodiments, the TDM **110** may provide warnings to the user that operating the DSD **104** at elevated temperatures may negatively impact a performance or longevity of the DSD **104**, and the user could elect to implement behavior modifications or to allow the DSD **104** to operate without behavior modifications.

FIG. 2 depicts a diagram of another illustrative embodiment of a system for temperature-based device operation, generally designated **200**. Specifically, FIG. 2 provides a functional block diagram of a disc drive data storage device (DSD) **200**. The DSD **200** may be a data storage device such as the device **104** shown in FIG. 1. The data storage device **200** can communicate with a host device **202** (such as the host system **102** shown in FIG. 1) via a hardware/firmware based host interface circuit **204** that may include a connector (not shown) that allows the DSD **200** to be physically removed from the host **202**. The buffer **212** can temporarily store user data during read and write operations and can include a command queue (CQ) **213** where multiple pending access operations can be temporarily stored pending execution. A non-volatile solid state memory **203**, such as Flash memory, can be included for additional cache or buffer memory, or to provide additional data storage for the DSD **200**.

The DSD **200** can include a programmable controller **206** with associated memory **208** and processor **210**. The controller **206** may also include a temperature detection module (TDM) **214**, which may be independent of the controller **206**, or part of the controller **206**. The TDM **214** may monitor temperature directly, or one or more temperature sensors **211** may be connected to the TDM **214** or the controller **206**. The TDM **214** and any temperature sensor(s) **211** may be situated to monitor the temperature at one or more locations in the DSD **200**. For example, a temperature sensor could be situated to monitor the temperature of a base plate, of a circuit board such as an E-block, of a read/write head slider, or of the head(s) **219** or laser(s) **215** themselves. Devices or components that perform other functions may also be adapted to act as a temperature sensor **211**; for example, components that monitor or control the fly height of the disc(s) **209**, coils **224**, or power monitors for the laser(s) **215**.

Further, FIG. 2 shows the DSD **200** can include a read/write (R/W) channel **217**, which can encode data during write operations and reconstruct user data retrieved from disc(s) **209** during read operations. A preamplifier/driver circuit (preamp) **218** can apply write currents to the head(s) **219** and provides pre-amplification of readback signals. The laser(s) **215**, such as those used by heat-assisted magnetic recording (HAMR) devices, may be a part of, joined to, or situated near to and operably controlled with the head(s) **219** to perform write operations on the disc(s) **209**. A servo control circuit **220** may use servo data to provide the appropriate current to the coil **224** to position the head(s) **219** and the laser(s) **215**. The controller **206** can communicate with a processor **222** to move the head(s) **219** and laser(s) **215** to the desired locations on the disc(s) **209** during execution of various pending commands in the command queue **213**.

The TDM **214** may be adapted to perform all the functions and processes discussed for TDMs herein; for example, monitoring temperature(s) within the DSD **200** and modifying a behavior of the DSD **200** when a temperature threshold is exceeded. In some embodiments, a behavior may be modified after a temperature threshold has been exceeded for a

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length of time. Modifications of operating behavior may include limiting processes of the DSD **200**, such as reducing background diagnostics, or changing the frequency at which data is written to the disc(s) **209** or nonvolatile solid state memory **203**. For example, the TDM **214** may direct that data write operations to the disc(s) **209** be made intermittently or not at all, and that excess data be written to the nonvolatile solid state memory **203**.

In another embodiment, the TDM **214** may modify a read-after-write operation. For example, when writing data to a data storage medium, the controller **206** may direct that a read operation immediately follow a write operation to verify the data was written. The read-after-write operation can enhance the integrity of the data since it enables a re-write of the data from a write cache if an error is detected. Thus, if there is an error in reading the data, the controller **206** may rewrite the data. However, if the TDM **214** has determined a temperature threshold has been exceeded, the controller **206** or the TDM **214** may direct that a data re-write operation occur at a different data storage medium than a previous data write operation. In a specific example, a first write operation may occur at the disc **209** (thus, using the HAMR technology and the laser **215** in the example of FIG. 2), a read-after-write verification may indicate an error in the written data, and a subsequent writing (i.e. re-write) of the data may be to the nonvolatile solid state memory **203**.

Referring to FIG. 3, a flowchart of an illustrative embodiment of a method **300** for temperature-based device operation is shown. The method **300** can include monitoring the temperature of a device, at **302**. The method **300** may involve determining if a threshold temperature has been exceeded, at **304**. If the temperature has not been exceeded, the method **300** may continue monitoring the temperature, at **302**. If the threshold temperature has been exceeded, the method **300** can involve modifying the operations of the device based on the temperature, at **306**. The method **300** may resume or continue monitoring the temperature, at **302**, after modifying operations of the device at **306**.

Modifications to the device operations at **306** may include any of the example behavior or operation modifications implemented by TDMs, or any other modifications that may be apparent to those of skill in the art. For example, the method **300** may limit processes of the device, such as preventing background diagnostics. In another possible modification of the operations, the method **300** may change the frequency at which data is written to one or more memories. In another example, the method **300** may reduce the frequency of write operations to a first magnetic disc memory, and write excess data to a second solid-state memory.

FIG. 4 depicts a flowchart of an illustrative embodiment of a method **400** for temperature-based device operation, as it may apply to a data storage device ("DSD"). The method **400** may apply to a data storage device with a first and second nonvolatile memory, such as the DSD **104** depicted in FIG. 1 or the DSD **200** depicted in FIG. 2.

The method **400** may involve monitoring a temperature of a DSD, at **402**. The method **400** may determine if a threshold temperature has been exceeded, at **404**. If the threshold temperature has not been exceeded, temperature monitoring may continue at **402**. If the temperature has exceeded the threshold temperature, the method **400** may direct that the DSD write data to a second memory, at **406**. This can involve a reduction or total cessation of data write operations to a first memory.

The method **400** may consider if the temperature has fallen below a threshold temperature, at **408**. This may be the initial threshold temperature considered at **404**, or it may be a second, lower temperature threshold; for example, an initial tem-

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perature threshold of 60° C., and a second, lower temperature threshold of 55° C. If the temperature has fallen below a threshold temperature, at **408**, the method **400** may move data from the second memory to the first memory, at **412**. If the temperature has not fallen below a threshold temperature, the method **400** may continue monitoring the temperature at **408** and the second memory space remaining at **410**.

The method **400** may consider if the second memory is nearing capacity, at **410**. If the second memory is approximately full, or has passed a data storage threshold, the method **400** may involve moving data from the second memory to the first memory, at **412**. If the second memory still has sufficient space remaining, the method **400** can continue monitoring the temperature at **408** and the second memory space remaining at **410**.

Once a condition has been met such that the method **400** directs that data be moved from the second memory to the first memory, at **412**, the method can re-evaluate whether the temperature of the DSD exceeds a threshold value, at **404**. If the temperature still exceeds the threshold value, data can continue to be written to second memory, at **406**; otherwise, the method **400** may resume monitoring the temperature at **402**.

The steps in the method **400** are presented in a specific order in FIG. 4. However, it should be apparent to one of skill in the art that additional steps may be included, or that some steps may be excluded or performed in a different order than that depicted in FIG. 4. For example, steps **408** and **410** could be performed in sequence in either order, or performed in parallel.

Referring to FIG. 5, a flowchart of an illustrative embodiment of a method **500** for temperature-based device operation is shown. The method **500** may apply to a DSD with a first memory and a second memory used as a buffer. The method **500** may monitor a temperature of a DSD, at **502**, and determine if a threshold temperature has been exceeded, at **504**. If the threshold temperature has not been exceeded, temperature monitoring may continue, at **502**. If the temperature does exceed the threshold temperature, the method **500** may direct that the frequency of writes to a first memory be changed, at **506**.

A change in write frequency may be accomplished by: modifying a value stored in a register, which register is checked by a controller to set a write frequency; implementing a function or instruction set in the DSD firmware; designating a buffer or second memory as the destination for data writes; setting a flag which determines write modes for the DSD; inserting breaks into the writable data stream; any other methods of modifying write frequency; or any combination thereof. The write frequency can be changed by increasing or decreasing the frequency of writes, or by setting a maximum duration of continuous write operations.

If modifying the frequency of data write operations to a first memory at **506** results in excess data that is not being written to the first memory, the method **500** can direct that excess data be written to a buffer when needed, at **508**. For example, if data is received at a rate higher than can be written to a first memory that is under a write frequency restriction, some or all of the received data can be written to a second memory, either temporarily or permanently. The excess data may be written to a cache memory or a second nonvolatile memory, such as nonvolatile solid state memory. For example, a write restriction may be imposed so that data may be written to the first memory for only 10% of drive operating time; the remaining 90% may be used to read from any memory, write to the second memory, remain idle, or other operations. In some embodiments, different writing restric-

tions may be imposed based upon a multiplicity of temperature thresholds, based upon a tiered threshold system. For example, at low temperatures data may be written to a first memory 100% of drive operating time; at a first temperature threshold, data writes may be restricted to 50% of drive operating time; at a second threshold, data writes may only be written to the first memory 10% of the time; and at a third threshold, data may not be written to the first memory at all, and data may only be written to the second memory.

Further, the method 500 may determine if the buffer is near capacity or above a threshold capacity, at 510. If there is sufficient space remaining, data can continue to be written to the buffer, at 508. If the buffer is near capacity or above the threshold capacity, the method 500 may move data from the buffer to another memory location, such as the first memory, at 512. Then, the method 500 can continue determining if the temperature of the DSD is above the threshold value, at 504, and direct that data be written to first memory or to the buffer accordingly, at 506 and 508.

The methods and devices described herein relate to temperature-based device operation, but other environmental factors may also be monitored, and device operation may be modified according to those factors. For example, environmental factors such as humidity, altitude, air pressure, physical shocks, or other factors may be monitored, and device operation can be modified according to those factors.

In accordance with various embodiments, the methods described herein may be implemented as one or more software programs running on a computer processor or controller, such as the controller 206. In accordance with another embodiment, the methods described herein may be implemented as one or more software programs running on a computing device, such as a personal computer that is using a disc drive. Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays, and other hardware devices can likewise be constructed to implement the methods described herein. Further, the methods described herein may be implemented as a computer readable medium including instructions that when executed cause a processor to perform the methods.

The illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments. The illustrations are not intended to serve as a complete description of all of the elements and features of apparatus and systems that utilize the structures or methods described herein. Many other embodiments may be apparent to those of skill in the art upon reviewing the disclosure. Other embodiments may be utilized and derived from the disclosure, such that structural and logical substitutions and changes may be made without departing from the scope of the disclosure. Moreover, although specific embodiments have been illustrated and described herein, it should be appreciated that any subsequent arrangement designed to achieve the same or similar purpose may be substituted for the specific embodiments shown.

This disclosure is intended to cover any and all subsequent adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the description. Additionally, the illustrations are merely representational and may not be drawn to scale. Certain proportions within the illustrations may be exaggerated, while other proportions may be reduced. Accordingly, the disclosure and the figures are to be regarded as illustrative and not restrictive.

What is claimed is:

1. A device comprising:

a first memory;

a second memory less influenced by variations in temperature than the first memory;

a temperature detection module adapted to:

measure a temperature of the device;

reduce a rate of storing data to the first memory without shutting down the first memory when the temperature exceeds a first temperature threshold;

redirect data intended to be stored to the first memory, but that cannot be handled by the first memory due to the reduced rate of storing, to be stored to the second memory based on the second memory being less influenced by variations in temperature; and

move data stored at the second memory to the first memory when the temperature falls below a second temperature threshold.

2. The device of claim 1 further comprising an interface, and the data intended for the first memory is received from a host at the interface, wherein a Logical Block Address (LBA) received from the host that is associated with the data is mapped to a physical location of the first memory.

3. The device of claim 1 wherein the device moves data stored at the second memory to the first memory when the second memory reaches a capacity threshold.

4. The device of claim 1 wherein the first memory is a disc memory and the second memory is a solid state memory.

5. The device of claim 4 further comprising a heat-assisted magnetic recording device to assist writing data to the disc memory.

6. The device of claim 1 wherein reducing the rate of storing data comprises reducing, but not eliminating, an amount of data written to the first memory and increasing an amount of data written to the second memory to compensate for the reduced rate of storing to the first memory.

7. The device of claim 1 comprising the temperature detection module further adapted to implement operating limitations for the device based on the temperature.

8. The device of claim 7 wherein the operating limitations include preventing background diagnostics from executing without shutting down the first memory.

9. The device of claim 1 wherein the temperature detection module is further adapted to:

determine a length of time the device operates above the first temperature threshold; and

reduce the rate of storing data to the first memory when the length of time exceeds a threshold time.

10. The device of claim 9 wherein the temperature detection module is further adapted to keep a log of the length of time and the temperature.

11. The device of claim 1 comprising the temperature detection module further adapted to:

reduce the rate of storing data to the first memory by storing a first portion of data intended for the first memory to the first memory and store a second portion of data intended for the first memory to the second memory.

12. The device of claim 1 further comprising the device configured to service all data read commands directed to the first memory with the first memory after the temperature exceeds the first temperature threshold.

13. A device comprising:

a data storage device including:

a first memory;

a second memory less susceptible to write errors at high temperatures than the first memory; and

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a controller configured to:

- detect a temperature of the data storage device;
- reduce a rate of storing data to the first memory without shutting down the first memory when the temperature exceeds a first temperature threshold; and
- store data intended for the first memory to the second memory due to the temperature exceeding the first temperature threshold.

14. The device of claim **13** wherein the data storage device is configured to:

- move data stored at the second memory to the first memory when the temperature falls below a second temperature threshold; and

- move the data intended for the first memory from the second memory to the first memory when the second memory reaches a capacity threshold, even if the temperature still exceeds the second temperature threshold.

15. The device of claim **13** wherein the controller is configured to reduce the rate of storing data by reducing, but not eliminating, an amount of data storage operations to the first memory and increase an amount of data storage operations to the second memory to compensate for the reduced rate of storing to the first memory.

16. A method comprising:

- detecting a temperature of a data storage device;
- reducing a rate of storing data to a first memory of the data storage device without ceasing operation of the first memory when the temperature exceeds a first temperature threshold;

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storing data intended for the first memory that cannot be handled by the reduced rate of storing to a second memory of the data storage device that is less influenced by temperature variations than the first memory.

17. The method of claim **16** further comprising:

- monitoring time values and corresponding temperature values; and

- modifying an operation of the data storage device based on the time values and corresponding temperature values.

18. The method of claim **17** further comprising:

- determining a length of time the data storage device operates above the first threshold temperature; and

- reducing the rate of storing data to the first memory when the length of time exceeds a threshold time.

19. The method of claim **16** wherein reducing the rate of storing data comprises:

- storing prevents storing the data intended for the first memory to the first memory; and

- moving data stored at the second memory to the first memory when the temperature falls below a second temperature threshold.

20. The method of claim **16** further comprising reducing the rate of storing data to the first memory when the temperature threshold has been exceeded and an error has been detected in the data written to a first memory.

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